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# Developing a projects evaluation system based on multiple attribute value theory

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**Abstract**

This paper presents the development process of an evaluation system to help the Portuguese Public Administration to choose a portfolio of projects for financing within the scope of Measure 1.5 of the Operational Program of the Portuguese Centro Region. The theoretical tool used is multiple attribute value theory, which focuses on the prescription of decisions in non-structured multiple objective decision scenarios. Problem structuring involved defining objectives in agreement with national development program and European Community policies, and attributes to measure the achievement of projects with respect to them. The approach required the assessment of value functions for each of the attributes, validation of independence conditions of decision makers and, finally, the aggregation of single attribute value functions into an overall multiple attribute value function (OMVF). All these structuring steps were carried out based on the preferences of a panel of decision makers with wide experience in managing and selecting projects within similar programs. The system developed, supported by a computer interface, is nowadays used to measure the appropriateness of projects to regional development goals; a project is chosen for financing if its value achieves the threshold. A portfolio of four projects embracing a range of characteristics rich enough to conclude about its performance illustrates its application.


*Keywords:* Public sector; Decision making; Multiple attribute value theory; Project selection

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## 1. Introduction

“Values are principles used for evaluation.” [1]

Values strongly characterize the human condition, particularly the ability to grasp and react to environmental changes, previous knowledge and experiences by taking simultaneous account of social, moral and ethical constraints. The importance of values in the decision-making process is therefore obvious, thus justifying that an important amount of effort spent in deciding should focus on value structuring and analysis. The use of values in public sector decision problems has become straightforward [2–4], with value-focused approaches providing decision makers with useful structuring that leads to substantially better decisions and improves their knowledge of main problem features.

A multiple criteria decision problem is one that, having a defined set of consequences (alternatives), *A*, a family of criteria depending on *A*, designated as *C*, and a set of preference relations *G*, intends to find a subset of *A* containing the best consequences, to assign the alternatives into predefined categories or rank them [5]. Each of these objectives defines a different multiple criteria problem: (a) selection; (b) classification or sorting; (c) ranking. Multiple criteria decision problems are included in a larger group of tools termed multiple criteria decision analysis whose goal is to provide decision makers with a formal framework to help them in solving problems with several values to consider. The philosophy behind these approaches is to allow the decision maker to capture, analyze and understand all the values involved in order to find a way to handle the decision problem. This perspective is called constructivist since it aims to build and structure the subjective values system [6]. Multiple criteria decision making has a more normative approach based on a different paradigm that assumes the existence of something (a formal construction) that allows the decision maker to find the best choices. This is done through a metric or using mechanisms based on the comparison of alternatives (outranking relations). The aim of these approaches is to observe the behavior of decision makers, help them to understand the decision problem, take account of all factors that influence the decision and prescribe the set of preferred solutions [7].

Multiple criteria decision-making tools have two basic approaches:

1. Multiple attribute methods aim to sort or rank a finite set of alternatives based on an explicit convex combination of all objectives of the decision maker [1,4]. Those methods, often called “selection approaches”, apply within frameworks characterized by a discrete and finite number of alternatives able to be completely grasped and compared by the decision maker with respect to all the attributes.
2. Multiple criteria methods aim to choose the optimal solution from an infinite number of feasible alternatives by solving a mathematical programming problem with objective functions and constraints subject to certain assumptions [8].

One of the families of multiple attribute methods, known as aggregation approaches, aggregates a set of discrete objectives into a single metric used to measure the performance of all the alternatives. The degree of achievement of the objectives is measured through attributes. The decision problem originated by these methods has implicit objectives and constraints, and a finite and discrete number of solutions (alternatives).Their dominant phase is the elicitation of single attribute value functions and the subsequent construction of the multiple attribute value function aggregating the preferences of the decision maker with respect to isolated objectives, which requires the validation of their independence conditions. Therefore, a multiple attribute decision problem is mathematically represented as the maximization of an objective function aggregating the subject’s preferences, $v(x)$, within a finite set of explicit alternatives, *A*, where

$x$ is the set of attributes that measures satisfaction with respect to the objectives, $x = [x_1, \ldots, x_N]$, and $N$ is the number of attributes considered. Notice that the maximum operator aims to represent the subject's pure rationality in the sense he/she intends to achieve an ideal. If decision scenarios are characterized by alternatives with complete certainty, which is common when the time horizon is limited or disregarded, a multiple attribute value function is sufficient to find the best alternative and the approach is similar to cost–benefit analysis. Indeed, it additionally needs the validation of the subject's independence conditions because of the non-comparability of the scales of attributes.

For decision problems involving risky scenarios, where alternatives are associated with probabilistic occurrences, the final metric is a multiple attribute utility function, with the concept of utility being introduced in order to aggregate the preferences of the subject and his/her attitude towards risk into one index [9]. The subjective utility is similar to subjective value functions, including an additional attribute, the uncertainty of consequences, taken as a loss [10]. There are several non-linear representational theorems that disaggregate the utility index into two different functions, one representing decision maker preferences and the other modeling his/her attitude towards risk [11–13]. Despite the mathematical beauty of those non-linear forms, the calibration of parameters is too complex, thus limiting its use in real decision problems, and giving prominence to utility functions that simultaneously account for risk attitude and preferences.

To apply multiple attribute utility theory (MAUT) two necessary conditions must hold:

1. The decision maker is able to set preference relations between pairs of alternatives with respect to every attribute.
2. The decision maker behaves with pure rationality in the sense that he/she intends to maximize the satisfaction with respect to each single objective.

In scenarios that involve complete certainty of alternatives, the utility is independent of the attitude of decision towards risk, leading to multiple attribute value problems. The axiomatic basis supporting the use of value functions is similar to MAUT, and is called MAVT. Similarly, the aggregation of single value preference functions into multiple attribute functions requires the validation of indifference relations between attributes. The necessary conditions required for this step are the ability of the decision maker to set preference relations, his/her consistency, and differential independence with respect to every attribute [1,14]. The theoretical basis provided by the independence conditions allows the formulation of the most important axiom of multiple criteria decision methods—if a subject prefers an alternative $a_1$ to another $a_2$, then the value he/she gives $a_1$ is higher than the value of $a_2$ [15]. That is, if $a_1 \phi a_2 \Leftrightarrow v(a_1) > v(a_2)$, where $\phi$ represents the preference operator, thus making it possible to transform the preferences space into the measurable space $\Re$ [14].

The form of the representational theorem that stands for multiple attribute value function is determined by the set of independence conditions validated for the decision maker. The most common is the additive model [16]:

$$v(x_1, x_2, \ldots, x_N) = \sum_{i=1}^{N} k_i v_i(x_i), \tag{1}$$

where $v_i(x_i)$ is the value function for attribute $i$, $k_i$ is the weight of attribute $i$ determined based on indifference relations between attributes elicited from the decision maker. Multi-linear [17] and multiplicative [18] models may also be used in real decision problems.

Over the years, several scientific works have provided strong evidence that decision makers behave most often according to bounded rationality, not analyzing all the alternatives to search for the optimal, but stopping the evaluation process when a satisfying level dependent on the resources available is met [19]. Instead of the ideal of achieving the maximization of satisfaction, it is more usual for the decision-maker to focus on getting the best solution, taking into account the resources available, time and effort [20]. Mathematically, this distortion of pure rationality is formulated by the existence of a threshold level $l$ for which any alternative with $v(x) > l$ is acceptable. In decision problems focused on the construction of portfolios of possible alternatives satisfying an acceptance level, pure rationality involves choosing several alternatives with a satisfaction level higher than a minimum threshold.

Methods such as MAVT lead to reproducible results, since different subjects with similar value functions yield the same solution. This point should carry a lot of weight in the clarification of social and political decisions affecting groups of citizens and equity achievement, and it is, indeed, the main reason for its application, justifying its appropriateness in those scenarios [21].

## 2. Motivation

Portugal entered the European Economic Community (EEC) in the early 1980s. To improve economic and social cohesion across the European Union, funds were made available by the Central Administration aiming:

1. to eliminate infrastructure development disparities around the country;
2. to eliminate identified competitive deficits;
3. to promote balanced development among regions.

In 1999 the EEC approved the 3rd Community Support Framework (3CSF) for Portugal, which is an aid plan devoted to structural and cohesion improvement covering the period 2000–2006 [22]. The EEC later promulgated an additional set of regulatory directives stipulating that the Portuguese Administration must respect community policies and guidelines for the application of structural funds received under the 3CSF [23]. That document also highlighted the need to maintain tight control on public expenditure to meet the obligations imposed by European Monetary Unit rules in relation to budgetary discipline. To improve the efficiency of the investment of funds at local scale, Regional Coordination Commissions were appointed as the institutions responsible for managing the transfer of Community funds and bridging its application with national development operational programs. The Commission for the Coordination of the Centro Region (CCCR) was nominated as the responsible for implementing these programs around the Portuguese Centro Region.

The Operational Development Program of the Centro Region comprises several financing sub-programs, here called measures, to manage the different structural funds according to the basic goals to be met [24]. Measure 1.5, called “Support for economic activities, effectiveness of public policies and territorial development actions”, commonly known as the Intangible Projects[1] of the European Regional Development Fund (ERDF), aims to eliminate the competitiveness disparity of the region by supporting the transfer of innovation into economic and social activities [25,26]. Facing the need to select a set of projects for

[1] Also recently known as Immaterial Projects of European Regional Development Fund.

financing under Measure 1.5, the CCCR decided to build an evaluation system to help the decision makers responsible for this task. The decision problem clearly falls into the multiple objective problems group, and the MAVT approach was chosen to deal with it. The basic purposes of the tool are:

1. To guarantee the equity and high standard of quality of the portfolio of projects approved for financing.
2. To make the application and management of the structural funds clear to all the agents involved in submitting, coordinating and supervising projects (e.g., regional, national and Community administrations).

The multiple attribute methodology was chosen because of the characteristics of the problem: implicit constraints and objectives, a finite number of alternatives and a satisfaction level required for approval. On the other hand, an operational method like MAVT was chosen for its capacity to represent the decision quantitatively with respect to each of the projects through a time-independent index representing its agreement with program objectives. The system will be used to select a set of projects to support on a yearly basis. However, the decision with respect to financing does not include the probabilistic occurrences associated with the projects' implementation. Given these assumptions, a multiple attribute value model is therefore suitable for the purpose.

## 3. Problem structuring

The first step in constructing the evaluation system was problem structuring, which involved identifying objectives, attributes, measurement scales and the assessment of single attribute value functions elicited from the panel of decision makers to represent the preference relations.

The objectives, listed in Table 1, were identified from European Community policies and corresponding priorities defined for the application of structural funds during the period 2000–2006 [22] together with strategic lines of the Operational Program of Centro Region.

The panel of decision makers used in the structuring task included a group of CCCR project managers involved in the evaluation and management of previous Community Support Framework (CSF) programs. To set the attributes for measuring the degree of achievement of each objective identified, brainstorming sessions were held. The results are summarized in Table 2. During these sessions the panel agreed on the

Table 1
Objectives of projects considered for financing within Measure 1.5

| Objective |
|---|
| 1. Maximize the innovation |
| 2. Maximize the geographical impact (economics of scale) |
| 3. Maximize the connection between partners and skills (networking effect) |
| 4. Maximize the number of direct beneficiaries (Enterprises, Citizens and other Organizations) |
| 5. Maximize the number of agents indirectly benefited (Enterprises, Citizens and other Organizations) |
| 6. Maximize the technical skills of employment (jobs created and maintained) |
| 7. Maximize the economic efficiency (economic sustainability) |
| 8. Maximize the synergies between actions (project integration) |

Table 2
Attributes of the decision problem

| Attribute | Designation | Scale | Minimum | Maximum |
|---|---|---|---|---|
| 1. Degree of innovation | $x_1$ | Dimensionless | 0 | 3 |
| 2. Geographic scale | $x_2$ | Dimensionless | 0 | 4 |
| 3. Number of partners | $x_3$ | Dimensionless | 0 | 4 |
| 4. Number of direct beneficiaries | $x_4$ | | | |
| 4.1. Enterprises | $x_{41}$ | 1 enterprise | 3 | 68 |
| 4.2. Citizens | $x_{42}$ | 1 citizen | 100 | 5080 |
| 4.3. Other organizations | $x_{43}$ | 1 organization | 3 | 30 |
| 5. Number of indirect beneficiaries | $x_5$ | | | |
| 5.1. Enterprises | $x_{51}$ | 1 enterprise | 3 | 3193 |
| 5.2. Citizens | $x_{52}$ | 1 citizen | 100 | 172 165 |
| 5.3 Other organizations | $x_{53}$ | 1 organization | 3 | 200 |
| 6. Number and level of education of jobs affected | $x_6$ | | | |
| 6.1. Jobs created | $x_{61}$ | | | |
| 6.1.1. High level | $x_{611}$ | 1 job | 0 | 4 |
| 6.1.2. Medium level | $x_{612}$ | 1 job | 0 | 4 |
| 6.1.3. Low level | $x_{613}$ | 1 job | 0 | 4 |
| 6.2. Jobs maintained | $x_{62}$ | | | |
| 6.2.1. High level | $x_{621}$ | 1 job | 0 | 4 |
| 6.2.2. Medium level | $x_{622}$ | 1 job | 0 | 4 |
| 6.2.3. Low level | $x_{623}$ | 1 job | 0 | 4 |
| 7. Economic efficiency | $x_7$ | | | |
| 7.1. Revenue-cost ratio | $x_{71}$ | Dimensionless | 0.0 | 1.0 |
| 7.2. Value of investment | $x_{72}$ | Dimensionless | 0 | 4 |
| 8. Number of integrated actions | $x_8$ | Dimensionless | 0 | 4 |
| 9. Decision maker classification | $x_9$ | Dimensionless | 0.0 | 1.0 |

need to include an additional attribute representing the classification given the project by the technique responsible for the evaluation, exploiting the experience-based knowledge accumulated. The construction of scales for every discrete attribute (Table 2) was done by directly interviewing the panel. The approach followed was to ask the decision makers to list and rank all the different types of project they expect with relation to each of the objectives, which yields a set of $n$ different project types. Afterwards, the measurement scale was set for each attribute, with the lower level corresponding to the poorly ranked type of project, which is given the level 0, and the upper being the most attractive type (level $n-1$).

The next step was the assessment of single attribute value functions and the calibration of weights to merge them into a multiple attribute form. As with the scales' assessment, the elicitation of single value functions was performed by oral interviews with each decision maker.

For attribute "Degree of innovation", a four-level discrete scale was agreed upon, corresponding to running activities, maintenance, modernization, and startup projects. The value function illustrates the preference given to projects with a higher degree of innovation (Table 3).

A five-level discrete scale was set to measure the attribute "Geographic scale" (Table 4).

Value function $v_2(x_2)$ highlights the importance given to projects with greater territorial impact, aiming to achieve benefits resulting from economics of scale.

Table 3
Value function for attribute “Degree of innovation”

| Project | $X_1$ | $v_1(x_1)$ |
|---|---|---|
| Running activities | 0 | 0.0 |
| Maintenance activities | 1 | 0.2 |
| Modernization | 2 | 0.6 |
| Startup | 3 | 1.0 |

Table 4
Value function for attribute “Geographic scale”

| Project | $x_2$ | $v_2(x_2)$ |
|---|---|---|
| Municipal scale | 0 | 0.0 |
| Over municipal scale | 1 | 0.4 |
| Regional scale | 2 | 0.8 |
| National scale | 3 | 0.9 |
| International scale | 4 | 1.0 |

Table 5
Value function for attribute “Number of partners”

| Number of partners | $x_3$ | $v_3(x_3)$ |
|---|---|---|
| 1 | 0 | 0.0 |
| 2–4 | 1 | 0.4 |
| 5–14 | 2 | 0.6 |
| 15–30 | 3 | 0.8 |
| More than 30 | 4 | 1.0 |

Although the use of a continuous scale was also discussed initially for the “Number of partners” attribute, a five-level discrete scale was again agreed on. The reason mainly concerned the extended profile of the projects expected, together with the inability of the panel to set the maximum limit of scale. The value function $v_3(x_3)$ (see Table 5) is meant to promote the networking effect between economic agents at regional and international levels and points up the interest in projects involving a large number of partners to enhance the use of available resources, productivity factors, and know-how.

Attribute 4 (Table 6) aggregates three sub-attributes corresponding to different types of potential direct beneficiaries: (a) enterprises; (b) citizens; (c) other social and non-profit-making organizations. The need to disaggregate such an attribute was caused by the requirement of the panel to weight each type of beneficiary differently, claiming that each has a different role in regional development and the attributes have scales with rather different magnitudes. The assessment of the value function for attribute 4 involved the construction of value functions for each of the sub-attributes. The minimum level of the scales for benefiting enterprises, citizens and organizations was set to 3, 100 and 3, respectively, while the maximum level was established based on regional development statistics, and was set to 10% of its value for the level

Table 6
Weights of sub-attributes included in the attribute “Number of direct beneficiaries”

| Sub-attribute | Designation | Weight ($k_{4j}$) |
|---|---|---|
| Enterprises | $x_{41}$ | 0.5 |
| Citizens | $x_{42}$ | 0.3 |
| Other organizations | $x_{43}$ | 0.2 |

3 territorial unit (NUTIII) with the worst development performance in the Centro Region [27]. Hence, the value functions for sub-attributes are given by

$$v_{41}(x_{41}) = \frac{x_{41} - 3}{68 - 3}, \tag{2}$$

$$v_{42}(x_{42}) = \frac{x_{42} - 100}{5080 - 100}, \tag{3}$$

$$v_{43}(x_{43}) = \frac{x_{43} - 3}{30 - 3}, \tag{4}$$

where $v_{4j}(\cdot)$ is the value function for sub-attribute $j$ of attribute 4. To aggregate the value functions relative to sub-attributes $x_{4j}$ into $v_4(.,.,.)$ an additive representational theorem was used with the weights calibration also taken from the panel (Table 6).

The value function for attribute 4 is therefore

$$v_4(x_{41}, x_{42}, x_{43}) = 0.5v_{41}(x_{41}) + 0.3v_{42}(x_{42}) + 0.2v_{43}(x_{43}). \tag{5}$$

During the elicitation process of single attribute value functions, the panel used their experience to list the profiles of projects expected, concluding that they would belong to two different types. The first would focus on citizens and other organizations (designated CO type), while the second would largely interact with enterprises and organizations (called EO type). This analysis shows that the expected projects could never simultaneously benefit all three types of entity listed, and consequently the maximum value of $v_4$ given by Eq. (5) could never be reached, which represents a bias for the evaluation system. To handle this problem $v_4$ was split into two forms—one applied when the beneficiaries are citizens and organizations, and the other when the beneficiaries' profile includes enterprises and organizations. The weights involved in these value functions are different from those presented in Table 6, because one of the attributes is disregarded. New trade-offs were determined by fixing the ratio between the remaining two equal to the value elicited for complete profiles and adding a constraint establishing that their sum is equal to 1.0. For type projects CO the value function becomes

$$v_4(x_{41}, x_{42}, x_{43}) = 0.6v_{42}(x_{42}) + 0.4v_{43}(x_{43}) \tag{6}$$

and for the EO profile it is

$$v_4(x_{41}, x_{42}, x_{43}) = 0.715v_{41}(x_{41}) + 0.285v_{43}(x_{43}). \tag{7}$$

The approach used to build the value function for attribute “Number of Indirect Beneficiaries” was similar to the one presented for attribute 4. The only difference lies in the ranges of the scales set. While

Table 7
Weights of level 2 sub-attributes of sub-attribute “Number and level of education of jobs”

| Level 2 sub-attribute | Designation | Weight ($k_{6ij}$) |
|---|---|---|
| High level | $x_{611}$ | 0.7 |
| Medium level | $x_{612}$ | 0.25 |
| Low level | $x_{613}$ | 0.05 |

the minimum values were maintained, the maximum values were set equal to 10% of total enterprises, citizens and organizations, respectively, of the Centro Region (NUTII). The trade-offs involved in the representational value function for attribute 5 are also similar to the weights assessed for attribute 4. The value function to use for projects with CO profile is

$$v_5(x_{51}, x_{52}, x_{53}) = 0.6v_{52}(x_{52}) + 0.4v_{53}(x_{53}) \tag{8}$$

and for projects with a EO profile is

$$v_5(x_{51}, x_{52}, x_{53}) = 0.715v_{51}(x_{51}) + 0.285v_{53}(x_{53}), \tag{9}$$

where

$$v_{51}(x_{51}) = \frac{x_{51} - 3}{3193 - 3}, \tag{10}$$

$$v_{52}(x_{52}) = \frac{x_{52} - 100}{172\,165 - 100}, \tag{11}$$

$$v_{53}(x_{53}) = \frac{x_{53} - 3}{200 - 3}. \tag{12}$$

The construction of the value function for attribute “Number and level of education of the jobs” was initiated by the assessment of value functions for level 2 sub-attributes. The measurement scale was agreed to be jobs created or maintained, with the maximum level set to 4 and minimum to 0 for all the categories. Therefore, for all level 2 sub-attributes the value function is

$$v_{6ij}(\cdot) = \frac{x_{6ij}}{4} \quad \text{with } i = 1, 2 \text{ and } j = 1, 2, 3, \tag{13}$$

where $i$ stands for the sub-attributes of level 2 of attribute 6, and $j$ for the sub-attributes of level 3 of sub-attribute $i$. An additive representational theorem was used to aggregate value functions of level 2 sub-attributes. The value trade-offs elicited are shown in Table 7, and illustrate the preference given to projects including the creation of graduate level jobs aiming to improve the skills of the labor force in the region and simultaneously to implement EC employment policies.

The value function for sub-attribute 6.1 is

$$v_{61}(x_{611}, x_{612}, x_{613}) = 0.7v_{611}(x_{611}) + 0.25v_{612}(x_{612}) + 0.05v_{613}(x_{613}). \tag{14}$$

The aggregation weights for level 2 sub-attributes into sub-attribute 6.2 (jobs maintained) are equal to the weights listed in Table 7, yielding

$$v_{62}(x_{621}, x_{622}, x_{623}) = 0.7v_{621}(x_{621}) + 0.25v_{622}(x_{622}) + 0.05v_{623}(x_{623}). \tag{15}$$

Table 8
Weights of the attribute “Number and level of education of jobs”

| Sub-attribute | Designation | Weight ($k_{6i}$) |
|---|---|---|
| Jobs created | $x_{61}$ | 0.7 |
| Jobs maintained | $x_{62}$ | 0.3 |

Table 8 presents the weights of sub-attributes of the attribute 6 highlighting the preference given to projects involving the creation of jobs.

The value function for attribute 6 is

$$v_6(x_{61}, x_{62}) = 0.7v_{61}(., ., .) + 0.3v_{62}(., ., .) \tag{16}$$

which leads to

$$v_6(.) = 0.49v_{611}(x_{611}) + 0.175v_{612}(x_{612}) + 0.035v_{613}(x_{613}) + 0.21v_{621}(x_{621}) + 0.075v_{622}(x_{622}) + 0.015v_{623}(x_{623}). \tag{17}$$

Attribute 7 measures the “Economic Efficiency”, and aggregates two sub-attributes: (i) the revenue-cost ratio that aims to measure the economic sustainability of projects bearing in mind that the financing of Measure 1.5 covers, at maximum, half of the costs; (ii) the value of investment as an indicator of the project’s scale of action and regional impact. Since real savings are not expected during the implementation of the projects the limits of the continuous scale of sub-attribute revenue-cost ratio are 0.0 for projects without revenue, and 1.0 for cases where revenues equal 50% of costs, the fraction eligible for financing by the EEC within 3CSF. Considering the time effect on projects, it is expected that some of them will be economically sustainable on a long-term basis.

$$x_{71} = \frac{\text{Revenue}}{0.5 \times \text{Cost}}, \tag{18}$$

$$v_{71}(x_{71}) = \frac{x_{71}}{1.0}. \tag{19}$$

At this point, the panel debated the financing policy, having agreed on the advantages of supporting a few consistent and highly integrated projects involving a striking level of synergy between the various activities and greater regional impact, instead of a larger portfolio of small projects. To encourage this policy, projects involving higher investment were favored. To measure the attribute “Value of the Investment” a scale with five discrete levels was used (Table 9).

The value functions for sub-attributes 7.1 and 7.2 were aggregated into the value function for attribute 7 through an additive representational theorem. The trade-offs are listed in Table 10 and denote the equal importance given to both economic sustainability and integration.

The value function for attribute 7 is therefore

$$v_7(x_{71}, x_{72}) = 0.5v_{71}(x_{71}) + 0.5v_{72}(x_{72}). \tag{20}$$

Attribute 8 measures the project integration in the sense that it evaluates the complementarity of all actions planned. The scale is discrete with 5 levels, and the value function is presented in Table 11.

Table 9
Value function for sub-attribute “Value of Investment”

| Project investment (€) | $x_{72}$ | $v_{72}(x_{72})$ |
|---|---|---|
| Less than 47 386 | 0 | 0.0 |
| Between 47 386 and 74 820 | 1 | 0.2 |
| Between 74 820 and 224 459 | 2 | 0.5 |
| Between 224 459 and 374 098 | 3 | 0.8 |
| More than 374 098 | 4 | 1.0 |

Table 10
Weights of the attribute “Economic efficiency”

| Sub-attribute | Designation | Weight ($k_{7i}$) |
|---|---|---|
| Revenue-cost ratio | $x_{71}$ | 0.5 |
| Value of the investment | $x_{72}$ | 0.5 |

Table 11
Value function for attribute “Number of integrated actions”

| Number of actions | $x_8$ | $v_8(x_8)$ |
|---|---|---|
| 1 | 0 | 0.0 |
| 2 | 1 | 0.4 |
| 3 | 2 | 0.6 |
| 4 | 3 | 0.8 |
| More than 4 | 4 | 1.0 |

The analysis of $v_8$ highlights the advantages given to projects including highly interconnected and complementary actions with respect to competences and goals.

Attribute 9 provides the decision maker with the ability to affect the evaluation process with his/her subjective classification, predominantly based on experience. The scale assessed was continuous, varying between 0.0 and 1.0, and the decision maker is asked to set the classification directly.

The validation of independence conditions led to the conclusion that the additive representational theorem stands for the representation of overall multiple attribute value function (OMVF), and approval is granted if the value achieves the financing threshold. That is

$$v(\cdot) = \sum_{i=1}^{9} k_i v_i(\cdot), \tag{21}$$

where $v_i(.)$ is the value function assessed for attribute $i$, and $k_i$ its trade-off. The assessment of weights $k_i$ was based on indifference relations expressed by the panel when asked to compare alternatives in which one of the attributes was changed at a time. The indifference relations established resulted in a set of equations that is solved together with the condition $\sum_{i=1}^{9} k_i = 1$, leading to the result presented in Table 12.

Table 12
Weights of decision attributes

| Attribute | Designation | Weight $(k_i)$ |
|---|---|---|
| Degree of innovation | $x_1$ | 0.1515 |
| Geographic scale | $x_2$ | 0.0758 |
| Number of partners | $x_3$ | 0.0758 |
| Number of direct beneficiaries | $x_4$ | 0.1515 |
| Number of indirect beneficiaries | $x_5$ | 0.0152 |
| Number and level of education of jobs | $x_6$ | 0.1515 |
| Economic efficiency | $x_7$ | 0.1515 |
| Number of integrated actions | $x_8$ | 0.0758 |
| Decision maker classification | $x_9$ | 0.1515 |

The values system of the panel shows the preference given to attributes 1, 4, 6, 7 and 9. Attributes 2, 3 and 8 have half of the importance of the first group and attribute 5 one-tenth, thus proving that indirect beneficiaries are not regarded as determinant in project evaluation. Asked to comment on such a result, the panel explained it as being due to insufficient knowledge to enable it to predict the benefits of indirect agents and the lack of ability to determine when it will be effective.

After problem structuring, the panel also set the approval threshold at 0.4. This limit, above 0.5, indicates an encouraging policy with respect to the submission of projects focused on innovation.

## 4. Test of independence conditions

According to Dyer and Sarin [14] the conditions to be validated to define measurable additive value functions are mutual preferential independence, difference consistency and difference independence. The methodology used to test them was to interview the panel through questionnaires designed to assess each one.

The preferential independence (condition 1) of the attribute 1 (*Degree of innovation*) with respect to all the other attributes and sub-attributes was tested by asking the panel to express a preference (or indifference) relation between two projects where only $x_1$ is varied, with all the other attributes fixed, that is, $x_i = \text{fixed}$, $i \in \{2, \ldots, 9\}$. Next, the level of one attribute $i \in \{2, \ldots, 9\}$ initially fixed, is changed and the panel is asked to compare the set of projects arising from varying $x_1$ into three levels (high, low and middle). Next, this procedure is repeated for three levels of all the other attributes, by changing the level of each, one at a time. Theory postulates that a decision maker is preferentially independent regarding $x_1$ when the preferential relations elicited are independent of its level. In the light of this axiom the questionnaire revealed that the panel is preferentially independent with respect to attribute 1 (*Degree of innovation*), and the combination of preference independence conditions between pairs of attributes allowed us to validate the mutual preferential independence. Gorman [28] presents a detailed analysis of the axiomatics standing of the validation of mutual preferential independence based on preference independence conditions between pairs of attributes.

The difference consistency (condition 2) was checked by asking the panel to set the preference relation between two projects, designated P1 and P2, respectively, with all attributes equal except one, for the sake of simplicity designated attribute *i*. Then, the panel was asked to set the preference relation between those two projects and a third project, P3, which is built from P1 by reducing the value of the attribute *i* to a level below the lower level it has in the lottery[2] {P1, P2}. Next, the experts were asked to indicate the preference relation between the strength of the choice of P1 within the pair {P1, P3} and of P2 within the pair {P2, P3}. The assessment of such a condition was based on attribute 1 (*Degree of Innovation*) which was changed between its worst and best levels. The difference consistency condition was validated since the panel revealed a preference for the alternative involving the project chosen from the first lottery {P1, P2} in all the comparisons of pairs of attributes. That is, if the panel prefers P1 to P2 in judging the lottery {P1, P2}, the strength of choice of P1 from the lottery {P1, P3} is higher than the strength of choice of P2 from {P2, P3}.

The test of difference independence was also based on the elicitation of a preference relation between two projects, P1 and P2, with only one of the attributes varied at a time. Afterward, a third and fourth project, called P3 and P4, respectively, were presented to the panel. Project P3 was built from P1 and P4 from P2 by changing one of the initially fixed attributes to a lower level. Next, the experts were asked to set the preference relation for the pair {P1, P3} and {P2, P4} and to compare the strength of the choice of P1 from the pair {P1, P3} with the strength of the choice of P2 from the lottery {P2, P4}. The reference attribute that was changed in the lottery {P1, P2} was varied at three levels (high, low and middle) and all other attributes were also changed (one at a time) within three levels. After a brief presentation of the purposes and usual biases of the questionnaire, most of the decision makers revealed difference independence regarding most of the attributes, with 85.4% validating the condition.

## 5. Application

The evaluation system described in the previous sections was implemented on a computer platform supported by a user-friendly interface (see Fig. 1). It was first customized and is now being used to help technical analysts at the CCCR in the selection of projects for financing. To illustrate the system's application we will described and discuss the profiles of four different projects submitted and analyzed. The project proposals discussed, designated here as P1, P2, P3 and P4, were chosen to illustrate the performance of the evaluation system with a large range of profiles, rich enough to provide a way to calibrate it. The following discussion relative to each proposal comprises the presentation of the profile, its evaluation using the OMVF (Section 5.1), and the interpretation of the system prescription by the panel of experts (Section 5.2).

### *5.1. Profiles of project proposals*

To test the evaluation system and validate it with the experience of the panel of experts we are briefly describing the profiles of four projects received and evaluated. These cases allowed the system prescription to be compared with the classification of experts, achieved through attribute 9.

*P1*: Project proposed by a wine cooperative, consisting of organizing a seminar to discuss general and technical aspects related to wine production and viticulture. It has a low impact on economics and

[2] Lottery holds for designating the comparison of two different projects in which a single attribute is changed.

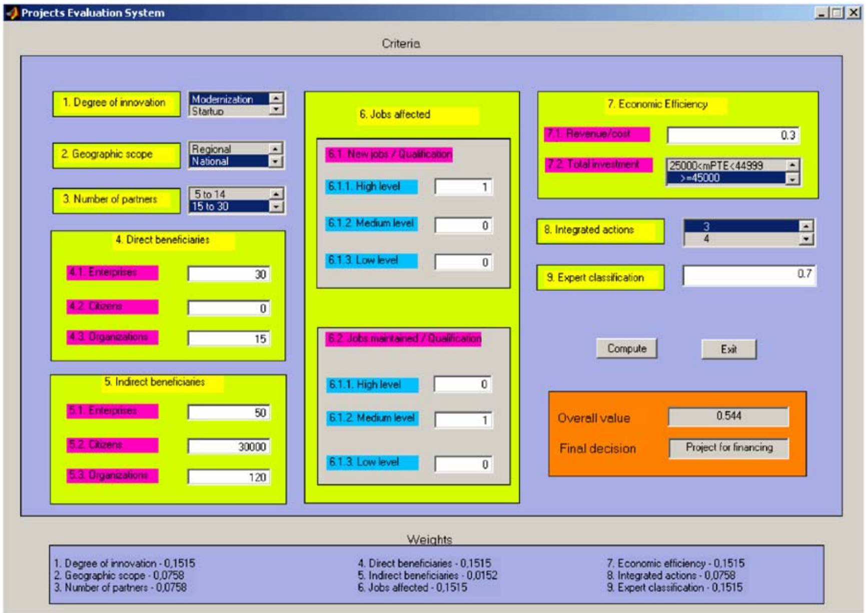


Fig. 1. Interface supporting the evaluation system.

competitiveness on a regional scale, and lack of innovation. (Total Cost = 94772€). The OMVF value achieved was $0.223 < 0.4$. Decision: project not approved for financing.

*P2*: Project involving cultural animation and dissemination of information, aiming at boosting the identity and image of the Centro Region and contributing to improving women's role in Portuguese society. It was proposed by a partnership of private and public regional agents, namely, municipalities, schools, other education institutions and art foundations. It consists of a series of art exhibitions, painting and sculpture workshops, crafts fairs, fashion and theatre shows, entrepreneurial seminars, and publishing information booklets, scheduled to take place during the course of one year over all region. (Total Cost = 319231€). The OMVF value achieved was $0.556 > 0.4$. Decision: project approved for financing.

*P3*: Project proposed by a local association, consisting of publishing two monographs on regional history and culture. The basic purpose was to reinforce community identity, and disseminate its culture and history on a regional scale. The project clearly has small impact, low economic sustainability, involving no innovation. (Total Cost = 231941€). The result of the OMVF value achieved was $0.232 < 0.4$. Decision: project not approved for financing.

*P4*: Project consisting of the creation of a pilot network composed of 22 organizations whose members include public institutions responsible for the production and use of digital cartography (municipalities and other public administration entities) and private organizations interested on the use of geographic information systems (GIS). The aim is to create a regional geographic information system (RGIS) able to renew and distribute data and new GIS contents at regional level in a sustainable (useful and efficient) way. The project shows a strong partnership, having a pilot and structuring role in land use planning and development by using GIS in public management actions at local and regional level, and may later be extended to the entire Centro Region. The result of the OMVF value achieved was $0.827 > 0.4$. Decision: project approved for financing.

### 5.2. Decision makers' interpretation of the results

When inquired to comment the ranking of the proposals P1 $(0.223) < P3(0.232) < 0.4$ (approval threshold) $< P2(0.556) < P4(0.827)$ and the overall multiple attribute value of each of the projects the panel of decision makers validated the results of the evaluation system. Furthermore, they noted that the system captured their perception of the quality and contribution of each project to the main objectives of this financing program with remarkable precision.

The projects not approved, P1 and P3, make only a small contribution to the objectives of Measure 1.5, since they are focused on maintenance activities, have no economic sustainability, mainly affect small communities, have high cost/benefit ratios, lack innovative actions and create no jobs. In view of this, those projects can only marginally improve competitiveness.

On average, technical staff classified the projects P2 and P4 as medium and very good projects, respectively, and selected them for financing, thus reinforcing the prescription of the system. The subjective value given by the techniques to projects slightly exceeds (about 0.1) the final OMVF result ($0.6 > 0.556$ in the case of P2, and $0.9 > 0.827$ in case of P4), proving the consistency of the system with the subjective evaluation carried out by experts.

## 6. Conclusion

In this paper, we have discussed the suitability of MAVT to solving public administration decision problems. The problem addressed is the construction of an evaluation system to apply when selecting a portfolio of proposals submitted to the Commission for the Coordination of the Centro Region (Portugal) for financing under the Measure 1.5—ERDF Immaterial Projects, within the 3rd Community Support Framework for Portugal.

Defining the objectives of the decision problem, the first task of problem structuring, involved bridging the EC policies for priorities in the application of funds in the period 2000–2006 and the strategic goals of the Operational Development Program of the Centro Region devised by Portugal's central administration. The definition of attributes and scales, and the testing of independence conditions, assessment of one-dimension value functions and calibration of weights were carried out by gathering information from the technical staff at the CCCR with experience of similar tasks in previous Community Support Frameworks. Throughout the structuring process, the panel agreed on the need to add a somewhat intuitive criterion (criterion 9) to express the subjective evaluation of the proposals and take advantage of the experience-based knowledge gained in previous CSF programs. To stimulate project submission the panel stated 0.4 as the threshold value for financing, aiming at encouraging innovative projects to narrow the regional competitiveness gap.

The system developed was implemented on a computational platform and is now being used in helping the decision task. The evaluation of four different projects covering a broad range of proposal profiles illustrates its application in the decision environment. The results prescribed strongly agree with the opinion of technical staff, thus validating the system's performance. During the evaluation of system performance, the panel claimed that their intuitive evaluation of a project's quality is, on average, slightly lower than the final OMVF value in projects not approved and higher in the projects approved. This may reveal an appreciation bias at the extremes of the quality scale successfully handled by the system. The panel considered the attribute "Number of direct beneficiaries" the most difficult to measure, largely because of the complexity of forecasting benefits in projects of an intangible nature covering a period of six years from the decision time. Moreover, the wide range of projects that are eligible increases the difficulty of setting the most appropriate ranges of scales for all the benefiting entities (Enterprises, Citizens and Other Organizations).

The use of Multiple Attribute Theory is a first step if the decision problem is to be structured. In decision problems concerning public administration, this task must be carried out in the light of development policies and strategic goals, allowing problem features to be understood and inquiring into the value system of subjects involved in the evaluation process and/or affected by decision implementation. Problem structuring consists of defining attributes and proper scales to measure the degree to which objectives are achieved, and eliciting the trade-offs between attributes. This step is predominantly constructive since it helps the decision maker by providing him/her with an understanding of the values and the ability to handle the problem. The development of decision systems to help the administration to choose projects for financing using public funds is highly recommended so that development policies can match the resources available, to achieve the maximum benefit. Furthermore, these tools make it possible to express the final decision as an index, which is reproducible and easy to understand by all agents affected by the decision, thus improving equity and social justice, as perceived in the implementation of public policies. The normative character of the decision prescription designed as an algorithmic procedure, supported by calibrated value functions and a strong theoretical mathematical basis, now available in the literature, all reinforce this idea.

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